Advanced Propulsion, Power, & Comm.
for Space, Sea, & Air

Software Defined Radio (SDR) Based Communication Downlinks for CubeSats

SWIFT SDR

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History and Motivation

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- **First TUI SDR was designed for relative navigation**
  - Tethered CubeSats
    - Relative position important for tether dynamics knowledge and active control
  - Fractionated Spacecraft (e.g. DARPA F6 clusters)
    - Collision avoidance
    - Relative position knowledge for orbit maintenance
    - Aid in pointing higher gain apertures
  - Distributed Sensing systems
    - Relative position knowledge for orbit maintenance
    - Timing for synchronized sampling
    - Knowledge of sensor baselines and orientations

SWIFT-RelNav Enables Cluster Operations

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- **Spacecraft subsystem that will enable a 'flock' of satellites to operate as a coordinated cluster**
  - Relative Position and Orientation for Formation Flight
    - Provide reference data for cluster-based sensors
  - Inter-satellite communication
    - Data exchange for cluster-based sensors
  - Cluster Timing Synchronization
    - Essential for coordinated operations and coherent measurements

	Kinematic GPS w/ UHF link	TUI's "Raw" SWIFT-RelNav
Relative Ranging Precision (1-σ)	0.1 m	**<0.1 m**
Relative Velocity Precision (1-σ)	10 mm/sec	**5 mm/sec**
Relative Attitude Precision (1-σ)	N/A	**1˚**
Relative Timing Precision (1-σ)	1 nsec	**0.3 nsec**
Comm Data Rate(BER≤10^{-6})	0.0192 Mbps	**>10 Mbps**
Range of Operations	< 10km	**<10 km**

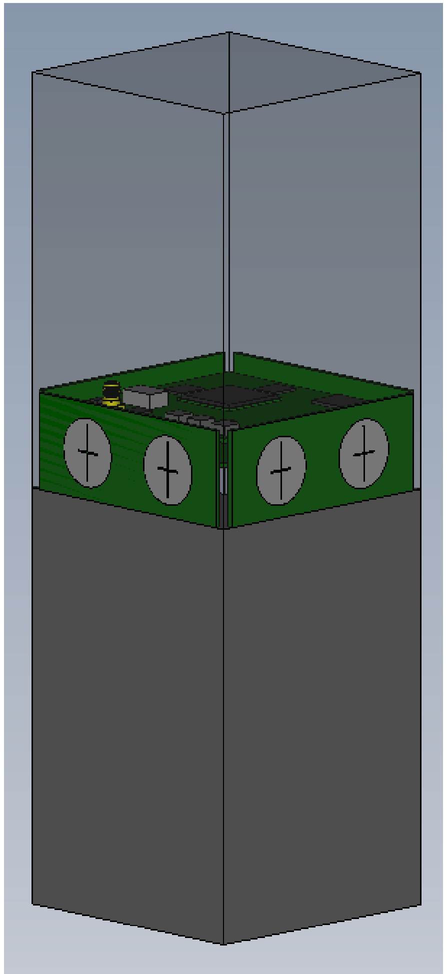
SWIFT- RelNav provides improved relative navigation, timing, and inter-sat comm over GPS-based methods to enable precision cluster flight and coherent sensing.

SWIFT-RelNav System Overview

- **Objective**
  - Provide cluster navigation, communication, and timing
- **Performance Targets**
  - RF-Based Relative Range & Heading sensor
  - < 0.1m range precision (1-σ)
    - TOF with PRN sub-sampling for range
  - < 1° attitude precision (1-σ)
    - Pseudo-Doppler Direction Finding for heading
  - Crosslink data rate > 12 Mbps (BER < 10-6)
  - Timing synchronized to < 20 ns (1-σ)
  - No sensor pointing required
  - No external references (i.e. GPS) required
  - Scalable to a large number of spacecraft
  - Specified performance up to 10km operating range

SWIFT-RelNav for CubeSat

- **CubeSat SWIFT-RelNav Configuration**
  - Single 8-element RHCP antenna array
  - Integrated precision oscillator and ability to interface to higher precision onboard clock/timing (e.g. GPS 1PPS)
- **For a 3 element Cluster with 1Hz update rate on range and attitude, with data communications 50% of remaining time**
  - Data Rate ≈ 6 Mbps
  - Size: 82 x 82 x 25 (H) mm
  - Mass: < 0.4 kg
  - Power: 4W average, 7W peak



Estimated SWIFT-RelNav Ranging Performance

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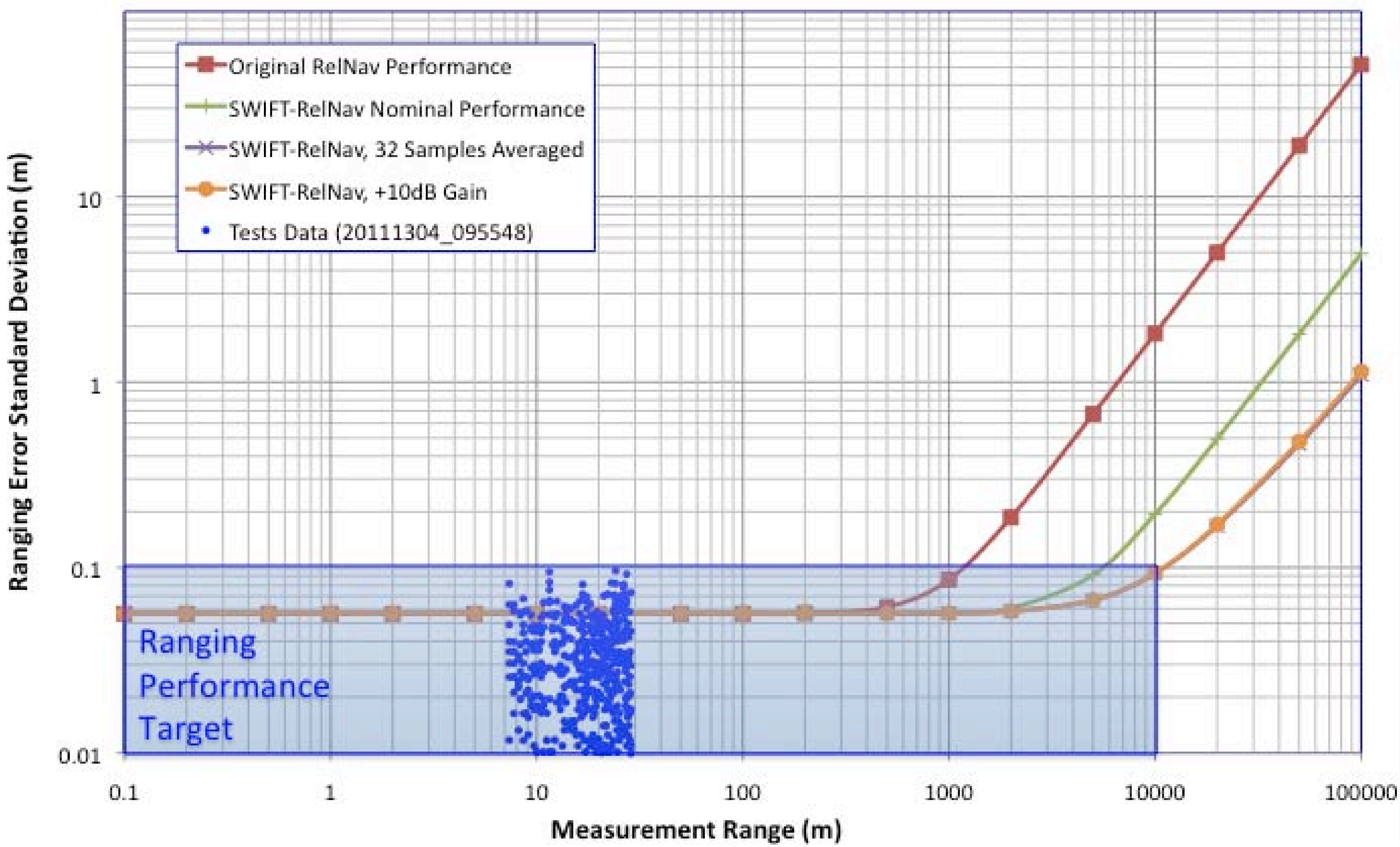


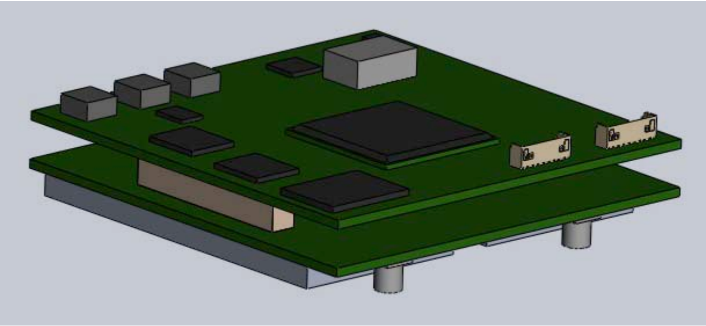
SWIFT-AFSCN Radio

- **AFSCN provides command, tracking, and telemetry support to assigned satellite mission (ICD-000502)**
- **SWIFT-AFSCN provides a programmable SGLS/USB radio to communicate with AFSCN ground stations**
- **SWIFT SDR architecture provides software control to key radio parameters**
  - Uplink & downlink frequencies (channels)
  - Waveform and modulation parameters
  - Feature set control (e.g. enable/disable command tone downlink, transmit sweep on/off)
- **Planning on implementing all (non-deprecated) modulations described in ICD**
- **Separated ‘command’ and ‘data’ interfaces to SWIFT-AFSCN radio to simplify interfacing**

SWIFT-AFSCN Specifications

- **Receiver**
  - SGLS: 1760-1840 MHz carrier range
  - USB: 2025-2100 MHz carrier range
  - Simultaneous reception on both bands possible
- **Transmitter**
  - S-band: 2200-2300 MHz, > 30 MHz BW, min 30dBm output
- **Integrated AES-256 encryption**
- **Coherent turn-around ranging**
- **Estimated SWaP**
  - Size: 82 x 82 x 25 (H) mm
  - Mass: < 0.4 kg
  - Power: 1.8 W receive
    6.6 W peak transmit

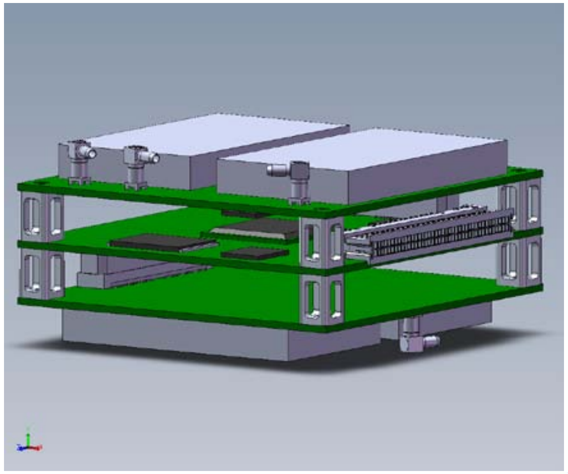
SWIFT AFSCN



AFSCN-TacSatComm

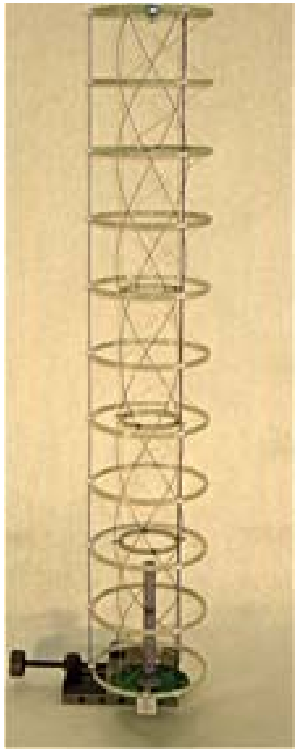
- **Started development of a communications *system* that would enable a nanosatellite to transmit/receive with an unmodified, standard Army issue handheld radio**
  - UHF frequencies (goal of up to 56 kbps)
    - > 4 W transmit power, with EIRP > 10 W
  - A S-band link is also desired
  - Integrated encryption and FEC
  - SWaP
    - Size: 0.5-1 U
    - Power: < 14.7 Watts
- **Radio thermal design is crucial**

SWIFT TacSatComm



SWIFT-TacSatComm Antenna

- **This a *system* – antenna really matters**
- **Plan is to use a deployable range-compensating quadrifilar helical (QFH) spacecraft antenna**
  - Gain pattern eliminates/reduces path loss effects when antenna nadir pointed
    - Reduces ACS requirements
  - Circular polarization pattern is good
  - Does not require ground plane
  - Nearby objects have little effect on antenna



- **UHF antenna ≈ 1 meter high**
  - Requires deployment

SWIFT-SDR Architecture

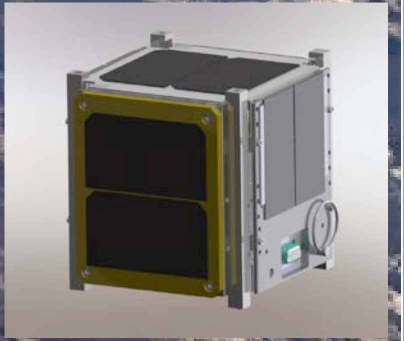
- **Architecture is comprised of hardware, firmware, and software elements**
- **Common modular interface to radio front ends allow system to have frequency band flexibility**
- **Common software interface enables rapid development and implementation of alternate channelization, configuration, modulation/demodulation, operations schemes**
- **Flexible user interfaces enhance testing as well as reduce integration challenges**

SDR and Comm System Development Lessons

- **When building hardware, design with margin**
  - The art of design comes in determining how much is enough, and not too much
- **Higher integration does not always produce a better system**
  - However, you must accept the cost of modularity
- **SDR radio development cycles are really software development cycles: good software engineering practices are crucial**
  - Software needs to be developed at all levels: firmware, device drivers, and user applications
  - Develop a library of test cases that you use throughout the development, test and deployment cycle
    - Don't forget off-nominal states!
- **Start with real signals as soon as possible**
  - COTS SDR Platforms (e.g. USRP) are readily available and affordable
- **Strive to improve performance through software first: greater flexibility, faster and usually less expensive**
  - However don't discount hardware problems either

Last, but not least….

…Yes, we still develop space tethers!



CubeSat Deorbit Module

http://www.tethers.com